Technology for an Earth Observing Deployed Lidar Telescope

Prof. Lee D. Peterson
Dr. Jason D. Hinkle
Joseph N. Footdale
Sungeun K. Jeon
University of Colorado

Dr. Syed Ismail
NASA Langley Research Center

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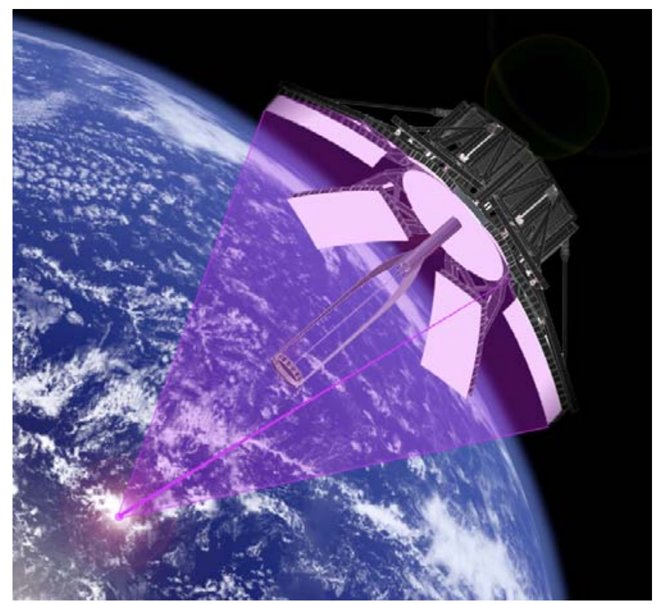


Presentation Outline

- Background and Project Overview
- Relevance and Impact
- Component Development and Verification
- Sub-System Verification Experiments
- Theoretical Modeling
- Conclusions

<u>Main Point</u>: Technology for passively configured, deployable optics for lidar-class instruments is (nearly) ready for flight system infusion.

Project Background

- University of Colorado (CU) is teamed with NASA LaRC on
  - 2002 ESTO Advanced Component Technology (ACT) project

    "Deployable Optics Modeling Experiments (DOME)"

    Contract NAS1-03009
- Project to be concluded summer 2006
- Project objective is to advance key technology for deployment of Earth-observing LIDAR telescopes

    Precision deployment

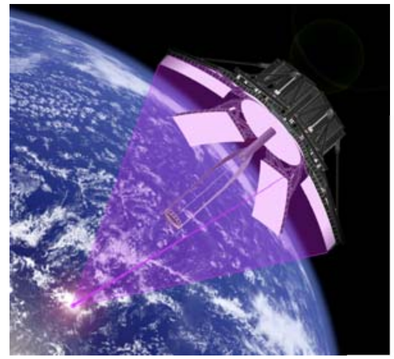
    Microdynamic stabilization

    Modeling technologies

    All verified through experiments
- Project embodies 12+ years of development effort aimed at deployable optical structures
  - Derived in large part from the Micron Accuracy Deployment Experiments (MADE) ISS payload (~1997-2001)

DOME Project Elements

- Overall Objective
  - Develop and validate precision deployment technology for low-cost, optical-UV Lidar telescopes



System Concept

Sub-System Experiment

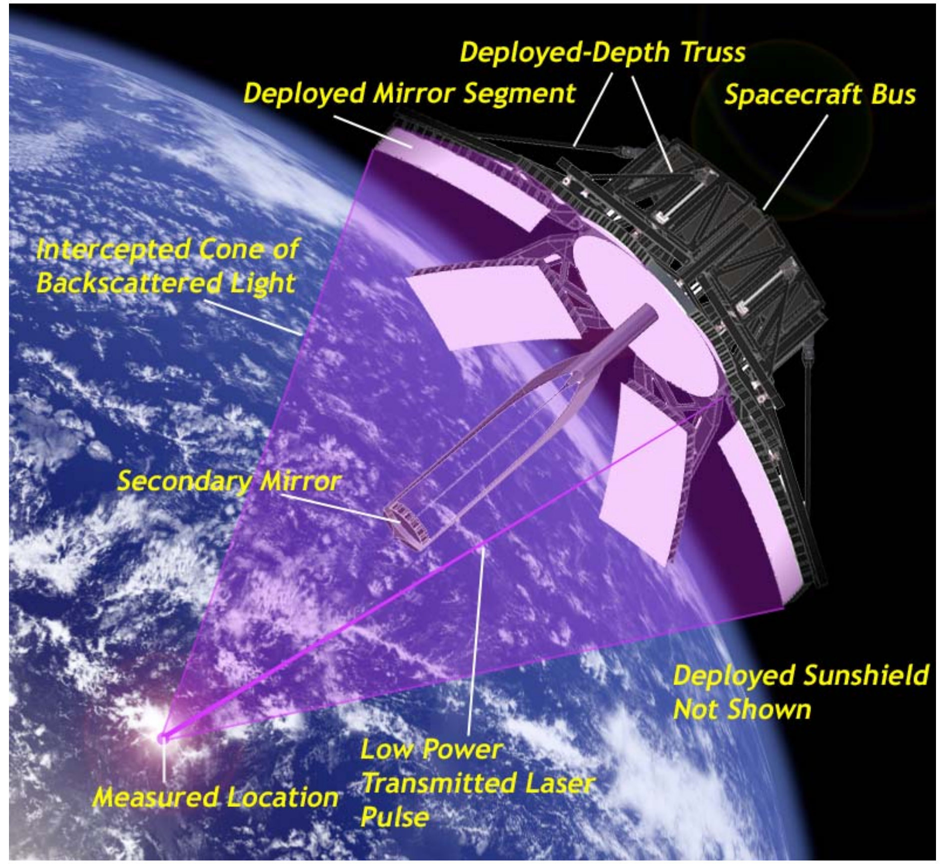
- Develop optical precision deployment technology
  - 10:1 to 100:1 improvement in structural performance

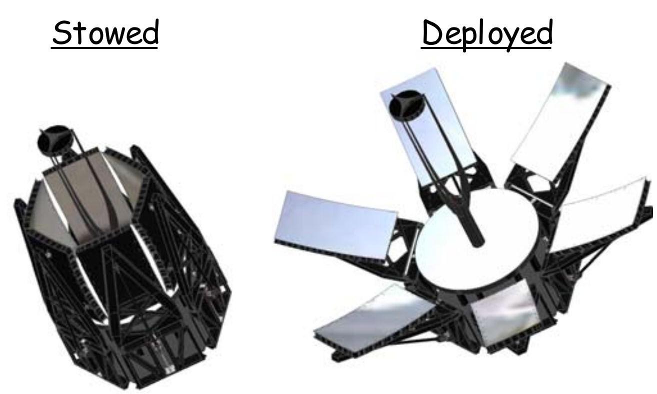
    Would minimize the need for active optical figure control

- Validate technology in component tests and a sub-system test
  - Component tests of mechanical hinges and latch
  - Sub-system test of a single petal and mirror segment
- Use integrated structural-optical models to extrapolate to full system flight behavior

DOME-Derived Flight System Concept

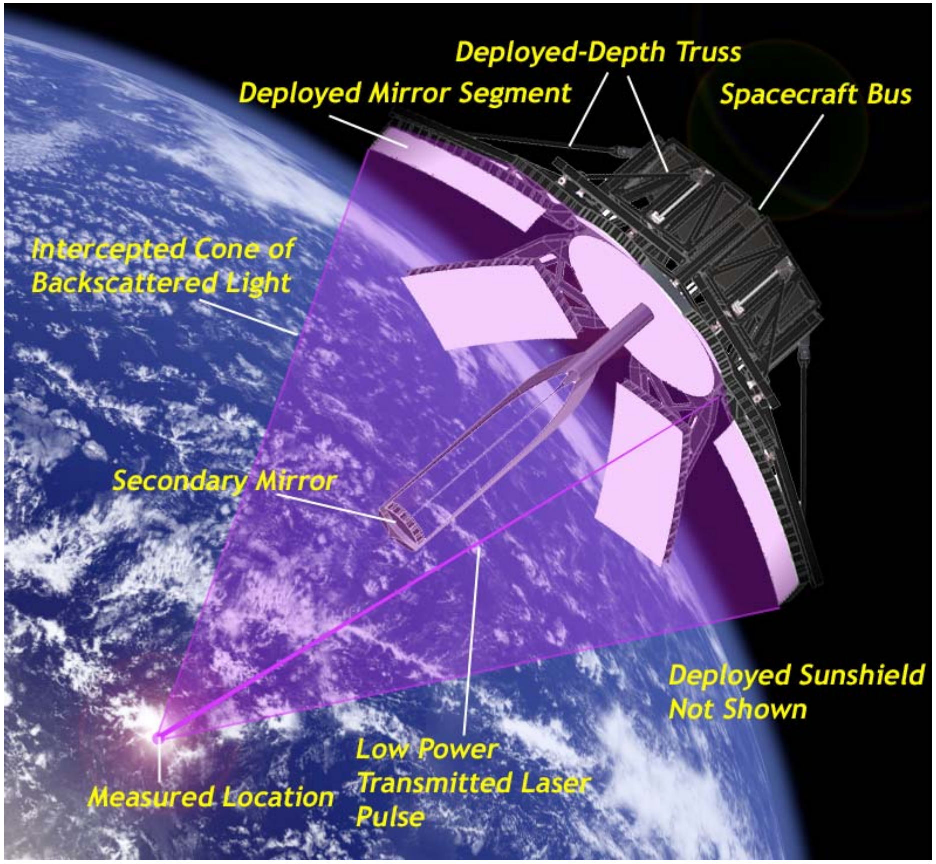
- Low cost deployed lidar telescope mirror
  - Pegasus-size package (2:1 deployed diameter)
  - Equivalent to Delta-II-size undeployed mirror
  - Saves tens of $M in launch costs
- Eliminates need for figure control of deployed petals
  - 10:1 to 100:1 improvement in structural performance through deployed depth reaction structure
- Mitigates higher power laser issues:
  - 4-10 times improvement in sensitivity
  - Power, size, cost, and risk
  - Heat dissipation
  - Eye-safety





DOME impacts key Earth Science missions

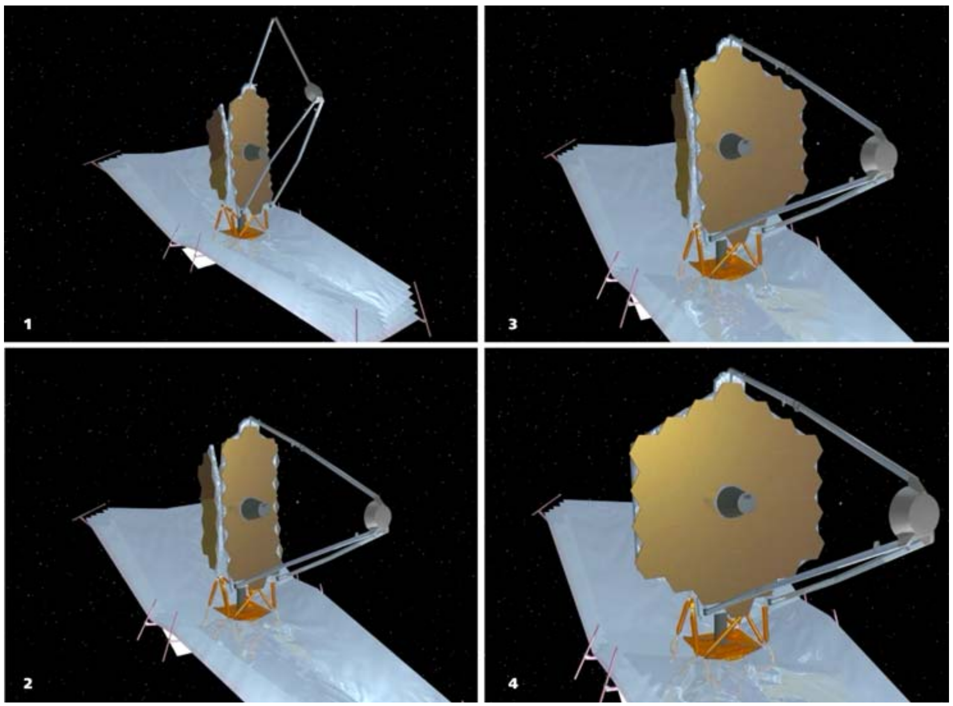
- Enables
  - Global tropospheric DIAL profiling of O3, H2O and CO2 with day or night coverage, absolute measurements and direct inversion capability
- Enhances
  - Global scale lidar profiles of aerosol and cloud optical and microphysical properties
  - Global wind (direct detection)
  - Global oceanographic lidar
- Applications
  - Better understanding of Earth's atmospheric system
  - Improves capability for predicting climate and weather
  - Atmospheric composition and dynamics, and air quality
  - Water and energy and global carbon cycles



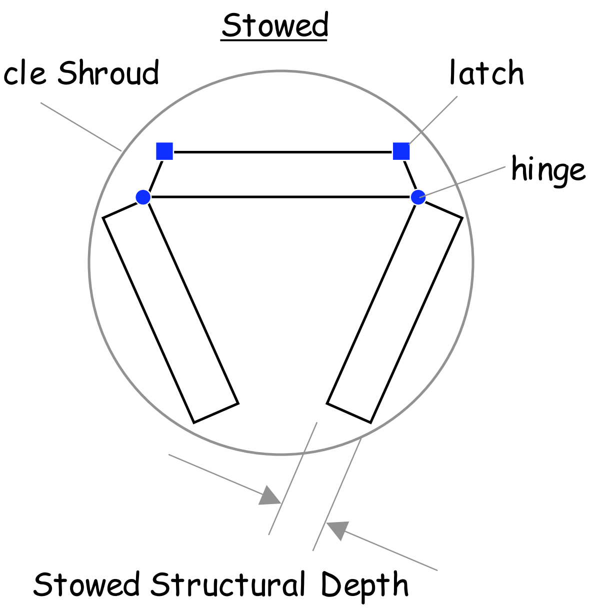
DOME technology also supports other space science missions that would require a deployed optic.

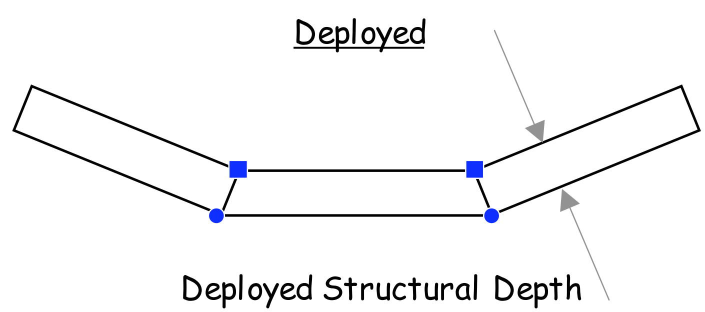
Structural "depth" or "thickness" is a key to overall structural stability

JWST Mirror Deployment

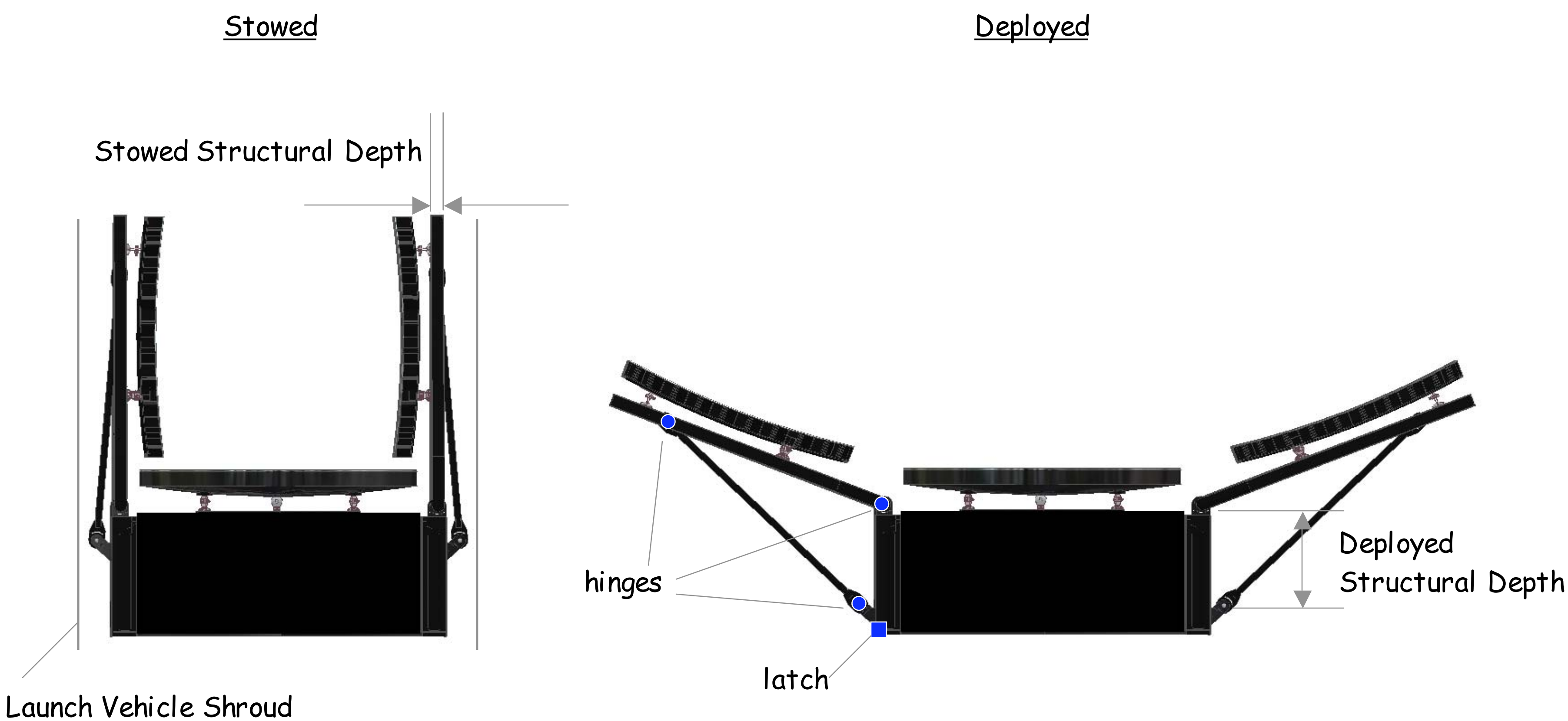


http://jwstsite.stsci.edu/gallery/deploy_graphics/lg_mirror_deploy.tif (2003-09-09)



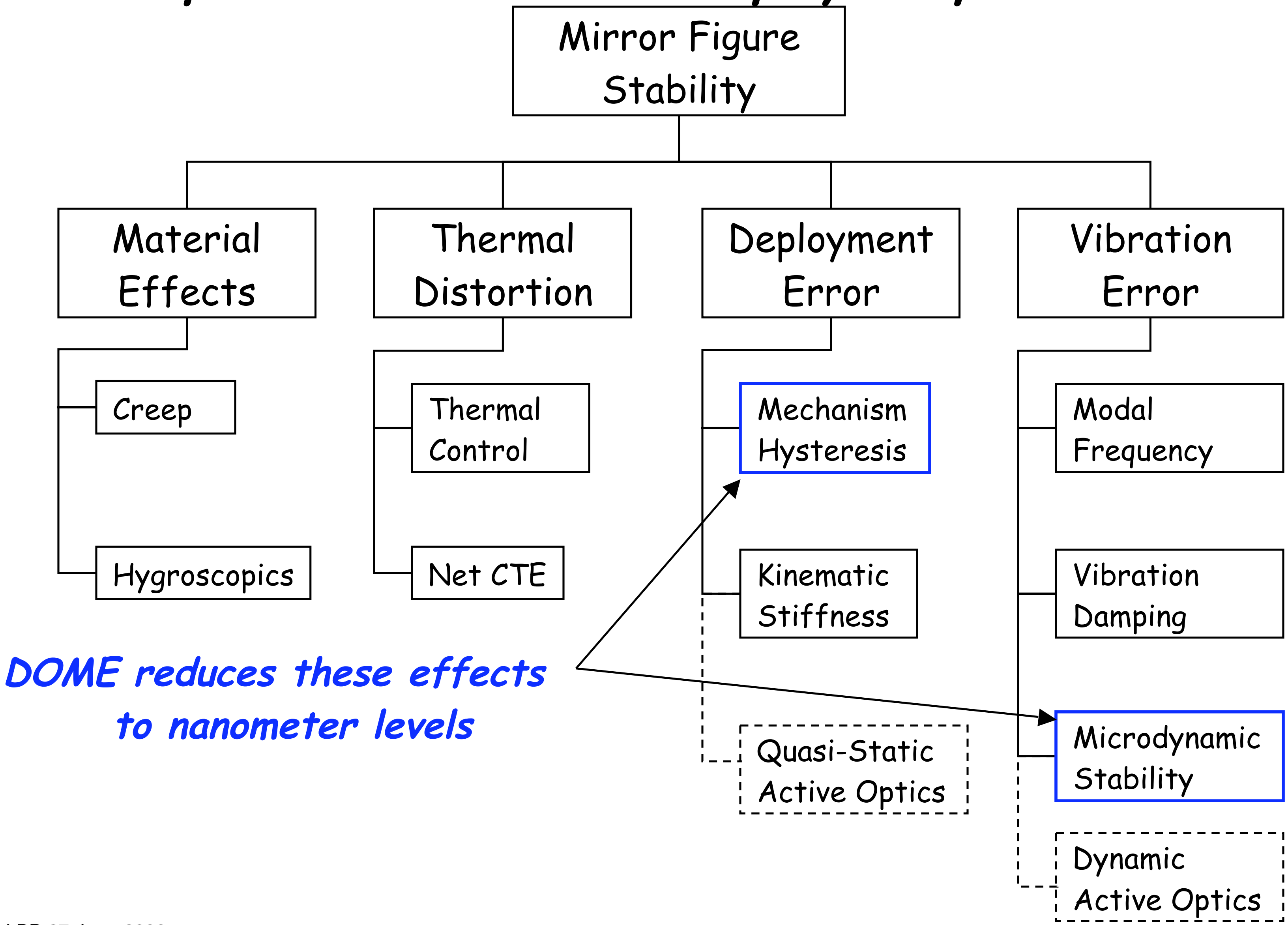


DOME will enable a folding scheme with deployed structural depth



Key to deployed depth: More degrees of freedom → More mechanisms

DOME technology intends to make deployed optics as stable as undeployed optics

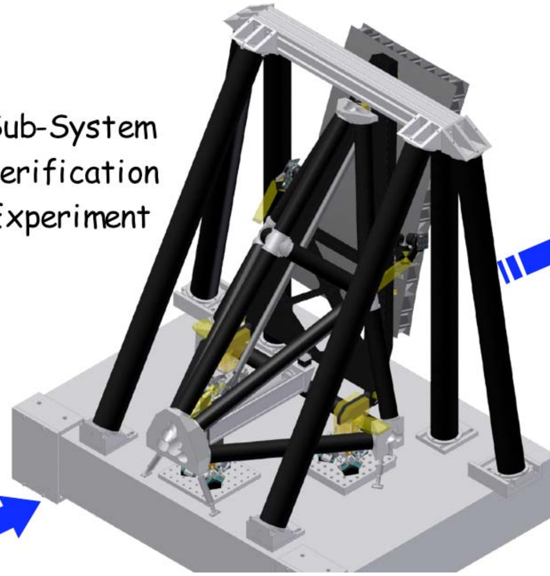


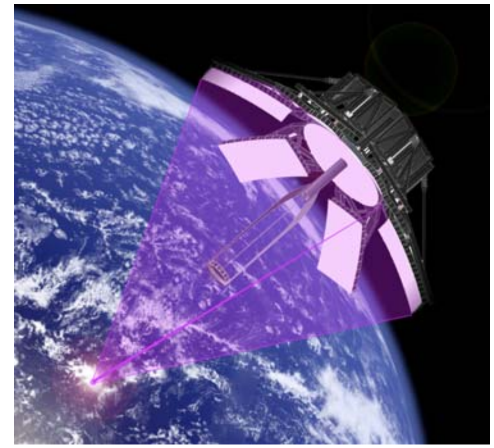
Single Petal Test Article

- Developed by Composite Optics, Inc (now ATK-COI) under SBIR contract ~1998
  - Mechanisms designed by M.S. Lake *et al* at NASA LaRC
  - Design heritage back to CU theses and prior experiments ~1995
- Preliminary experiments
  - ~+/- 200 nm repeatability in transverse axis
  - ~+/- 8-10 micron repeatability in deployment direction
- DOME project to complete development and verification of the technology embodied in this test article

DOME flows extrapolates from components to sub-system, and to flight system

Sub-System
Verification
Experiment



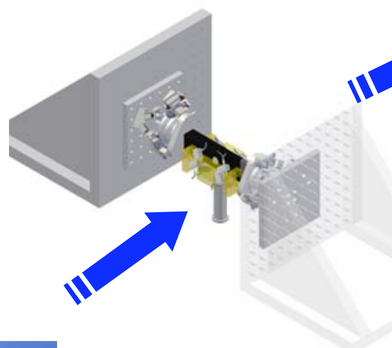


Flight System Model

$$M\ddot{q} + D\dot{q} + Kq = Q$$
$$\dot{y} = f(y,q)$$

$Note: g = 0$

Component Verification
Experiments



Precision
Mechanism
Components

Sub-System
Model Update

$$M\ddot{q} + D\dot{q} + Kq = Q + g$$
$$\dot{y} = f(y,q)$$

Component
Model Update

$$\dot{y} = f(y,q)$$

Model uncertainties will be correlated with experimental uncertainties and propagated to the flight system model.

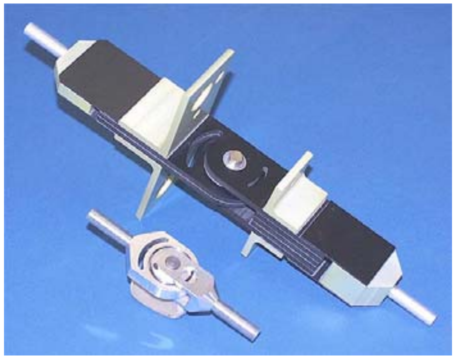
Development of Precision Hinges and Latches

- Design Approach
  - Regulate the transmission of stress through the mechanism to avoid the effects of friction
  - Predictable behavior by design
- Design Features
  - Mechanism hysteresis comparable to material hysteresis and creep
  - Overall stiffness and mass the same as the corresponding monolithic material

No net impact of deployment mechanisms

LaRC 1995

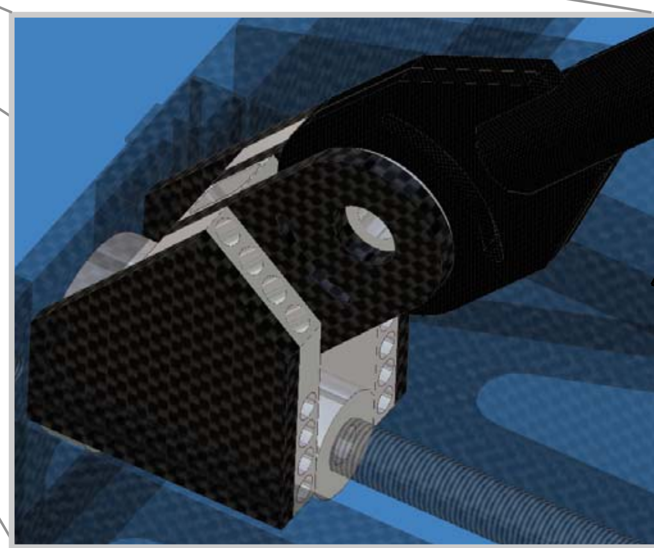
LaRC & COI 1997



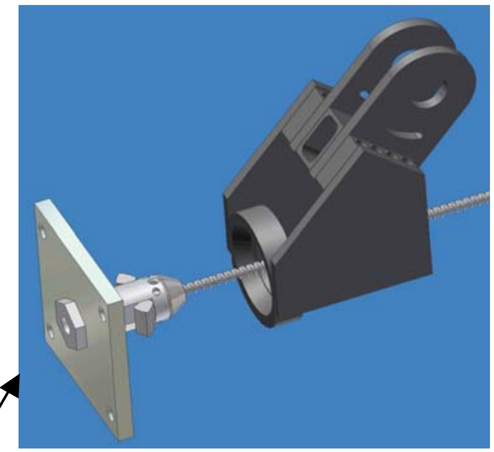
CU 2006

Latch reconfiguration allows for controlled (variable) preload employing deployment actuator

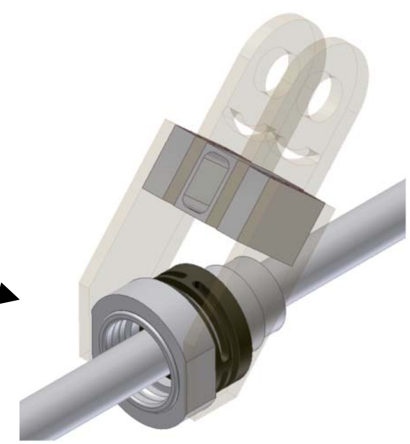
Single Petal Assembly



Traveling Latch Mechanism

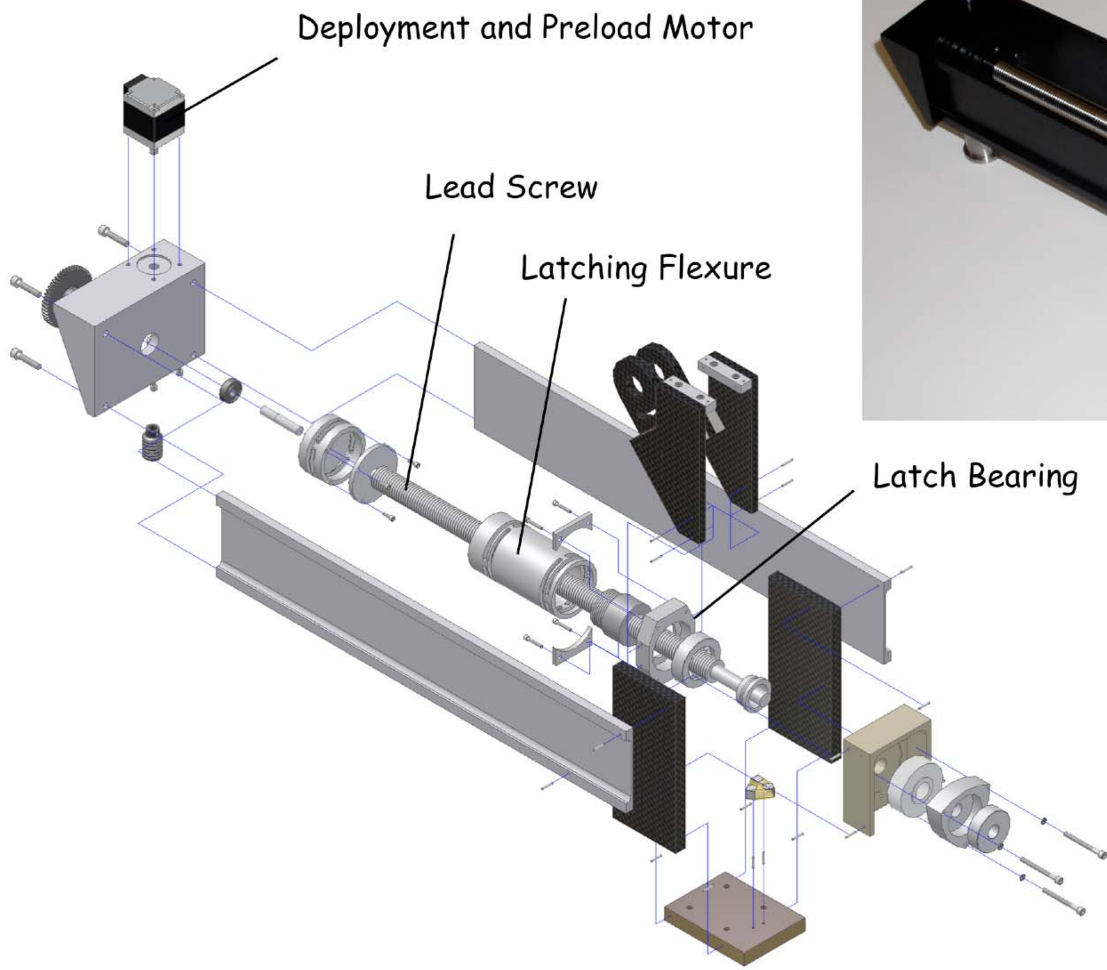


Orig. Design: Two-line contact with constant spring-driven preload



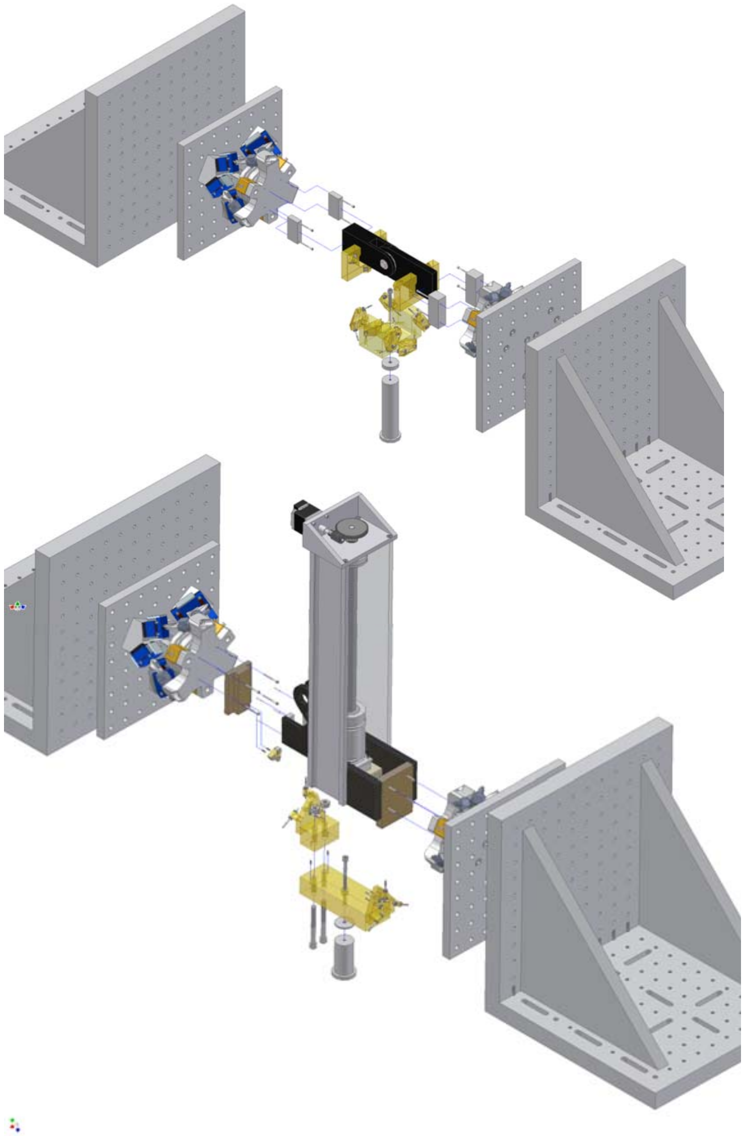
New Design: Angular contact bearing; ball screw-driven variable preload with compliant interface

Latch Detail

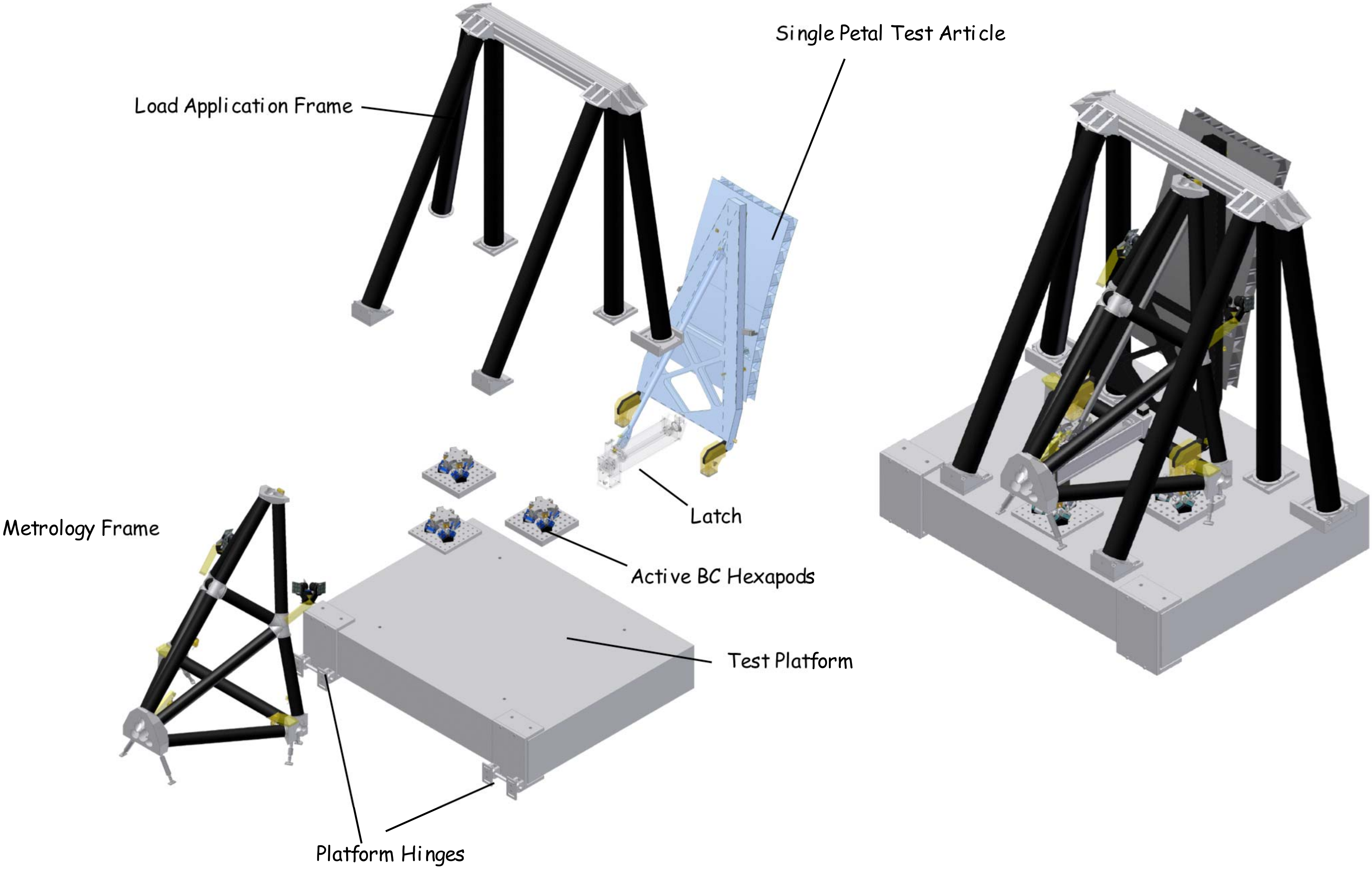


DOME Component Tests

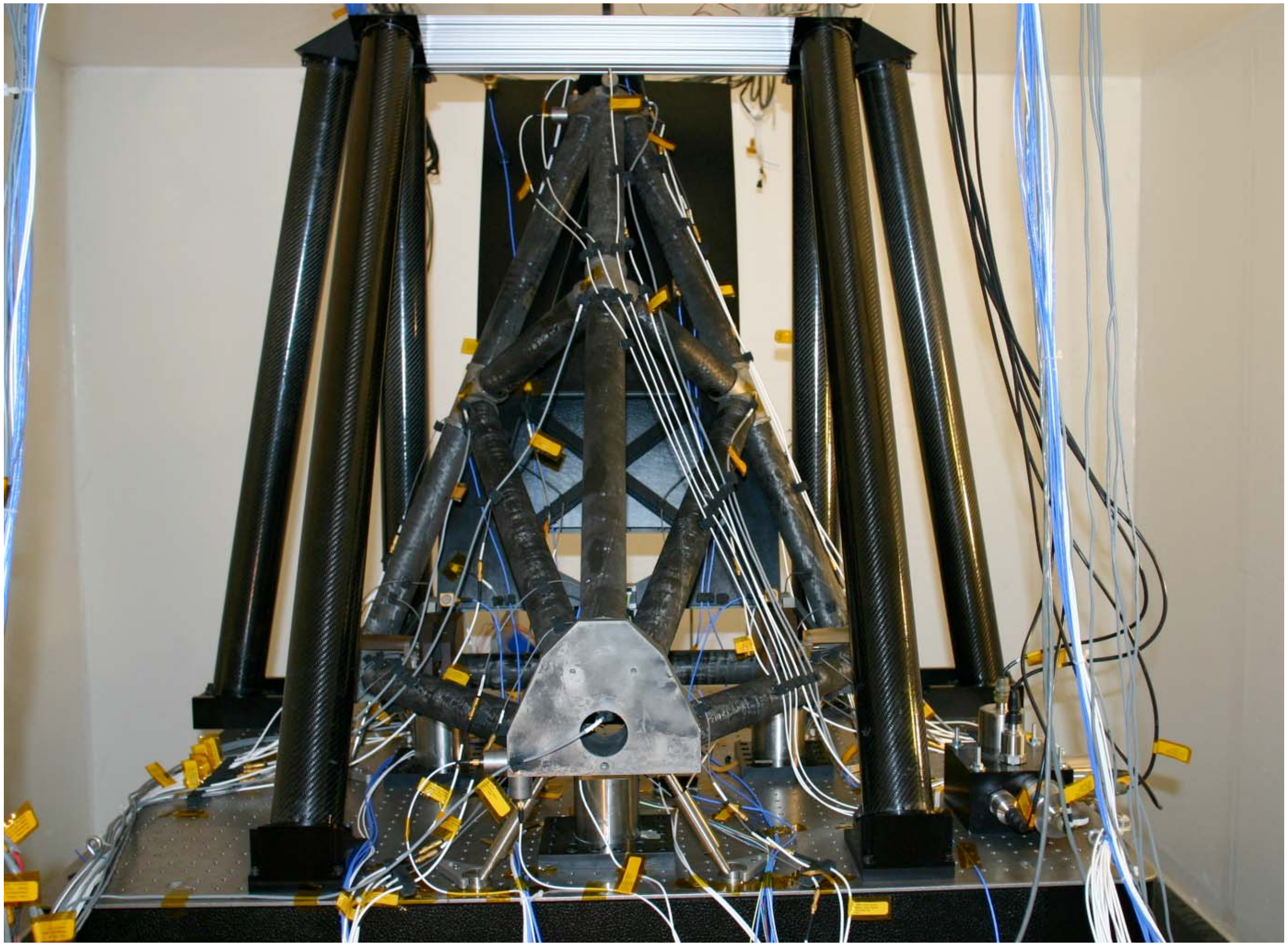
- Hinge Component Test (HCT)
  - Measures hysteresis and stability of hinge mechanism
- Latch Component Test (HCT)
  - Measures hysteresis and stability of latch mechanism
  - Study effect of variable preload
- Nonlinear mechanism models
  - Capture effect of friction and microslip
  - Based on contact mechanics (not empirical models)
  - Use for design and to establish flight system margins



Single-Petal Test Apparatus (SPTA)



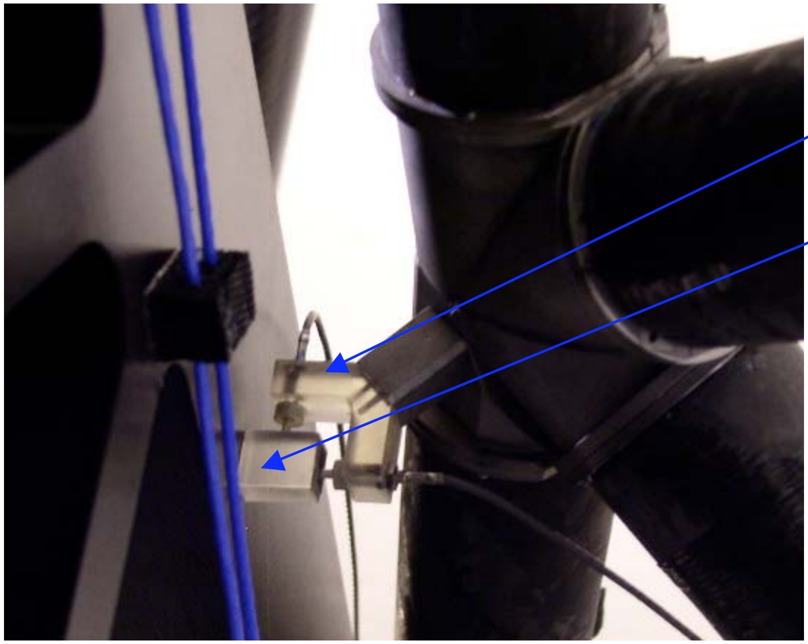
SPTA includes > 150 sensors for displacement, vibration, force and temperature



Tests conducted inside micro-gee and milli-K test chamber

Metrology provides stable measurement reference for both static and dynamic sensing

Nanometer-precision displacement sensors measure the SPTA shape



ECS in zerodur mounts connected to MEF

Metallic targets mounted to SPTA strongback

Eddy Current Sensors (ECS) positioned and adjusted to 5.0+/-0.2 volts

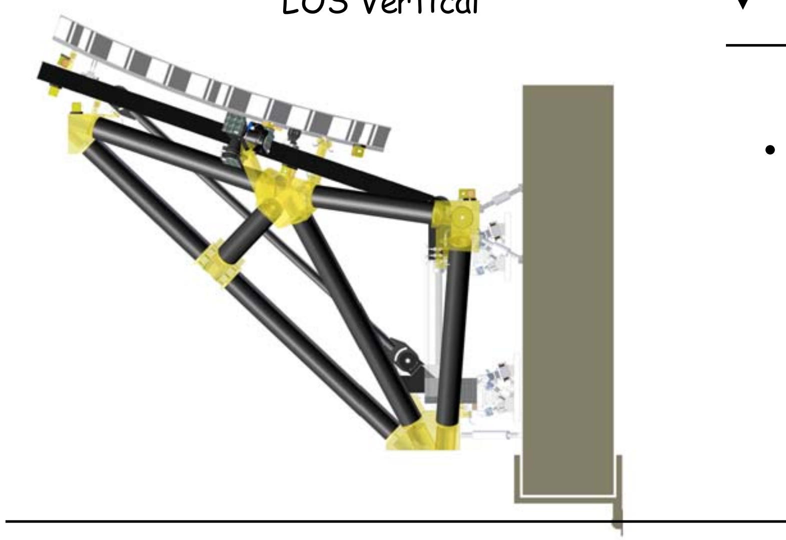
Optic figures of merit estimated from perturbational ray trace model

Sub-system experiments will be performed in two difference gravity orientations

- Test the ability to predict the effect of gravity preload on the nonlinear hinge and latch mechanics
- Entire test assembly can be reoriented intact

LOS Horizontal

LOS Vertical



- Will also apply external loads to simulate gravity preload and effects
    - Verify key hypothesis

Preliminary Deployment Repeatability Tests

- Conducted a series of mate-demate (i.e. "partial stow") cycles
  - Two latch preload control modes

    1) Closed-loop control of preload to +/- 0.1N

    2) Open loop command of deployment motor step position
  - *Assess*

    Post-deployment (thermal) creep stability (test time driver)

    Sensitivity to latch preload (magnitude and control mode)

    Need for various data sets (e.g. data during deployment)

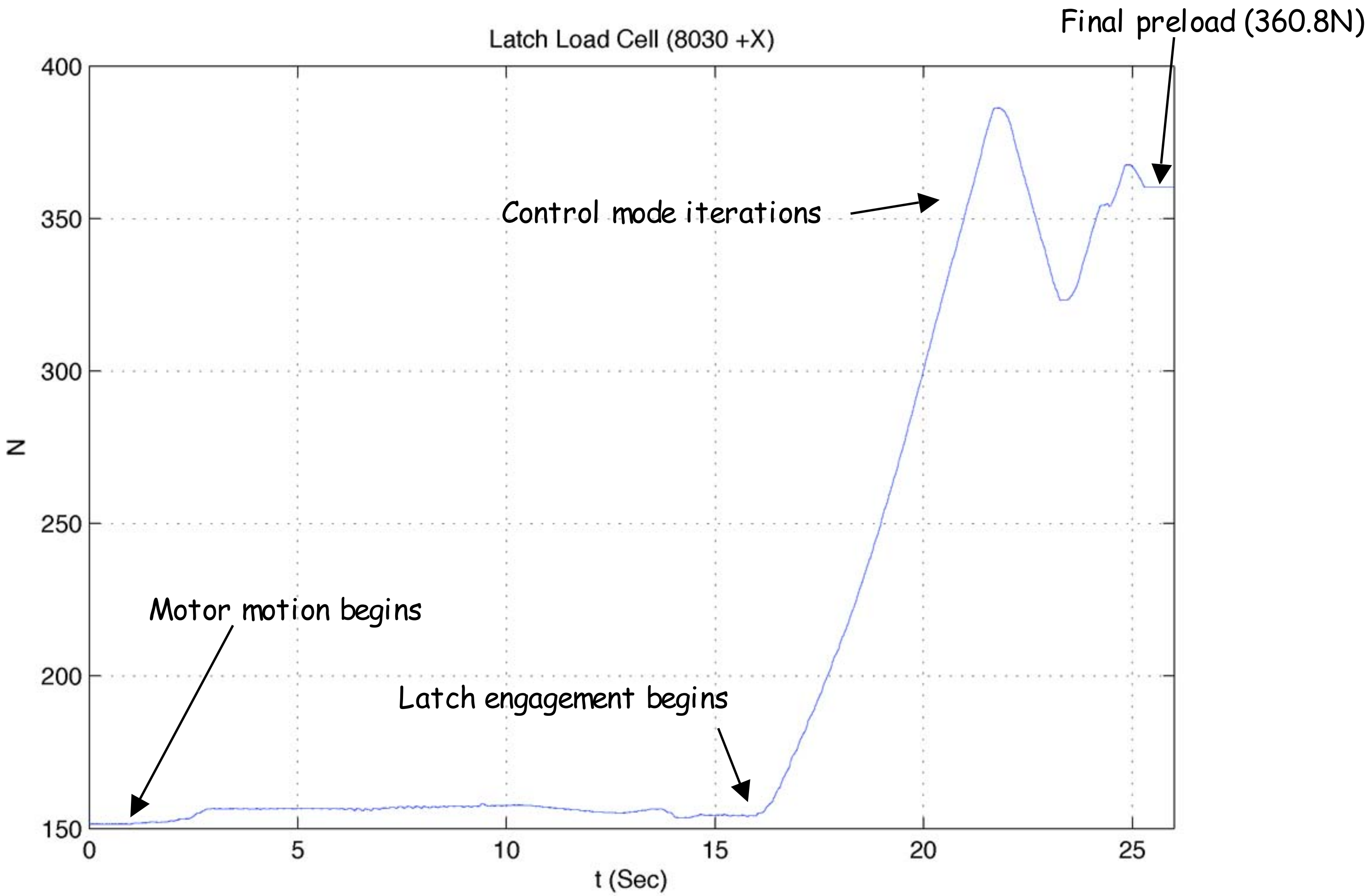
    Timing for post-deployment data windows

    Complexity of data reduction task (esp. for dynamic testing)

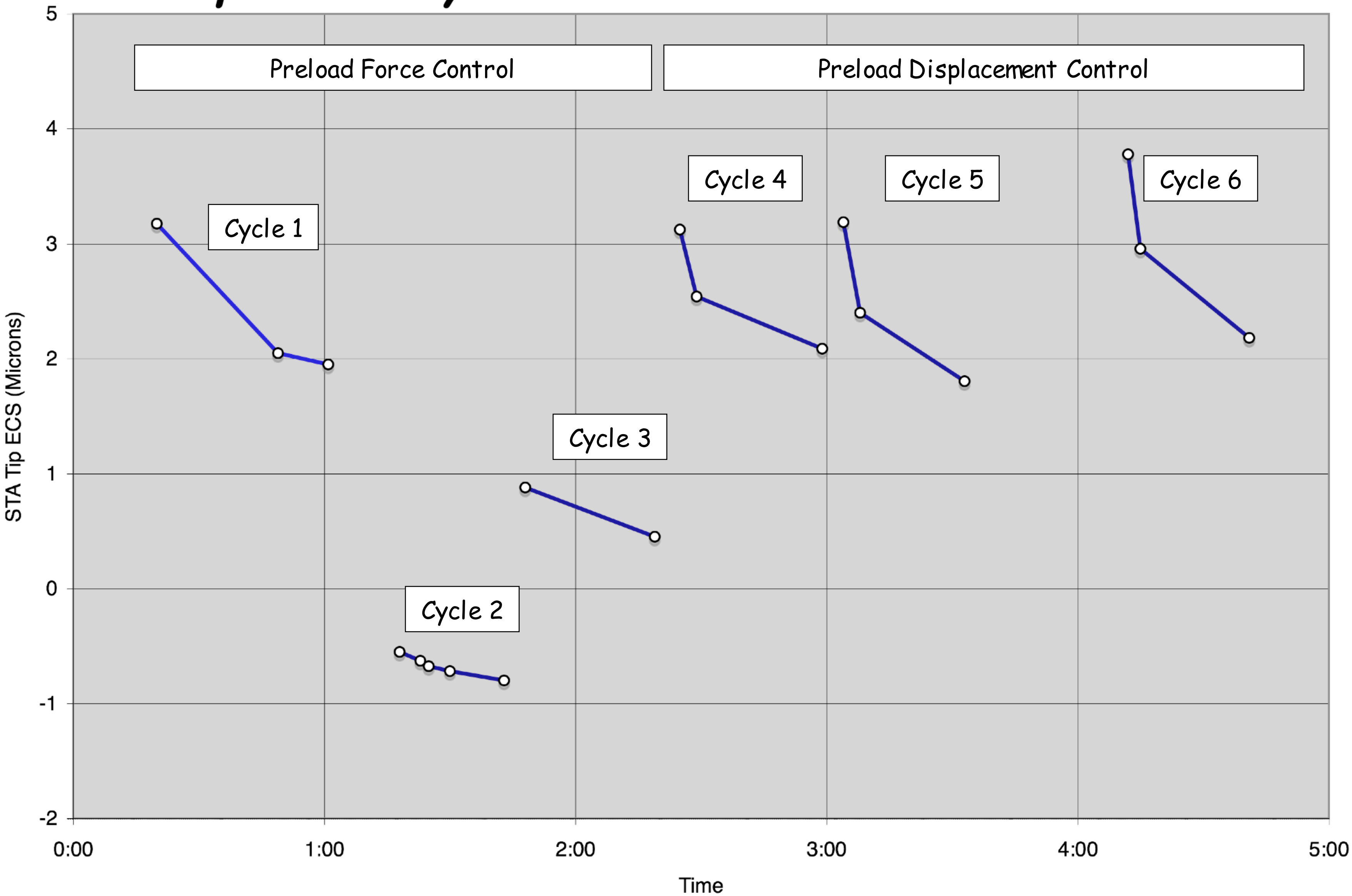
Summary of Initial Observations

- Initial system functional verification
  - Very low noise noted (nanometer resolution around hinges)
  - Extreme resolution (table rocking post-deployment seen in hinges)
  - Noted anomolous noise in selected ECS near base
- Test environment stability
  - MEF very stable after 1 hour close-out. Need to check RTD's
- SPTA environment sensitivity
  - Can resolve 10's of nanometer high vibrations induced by trucks, etc
- Deployment repeatability results are "encouraging"
- Post-deployment (thermal) creep stability (test time driver)
  - 1-hour stabilization appears to be necessary
- Sensitivity to latch preload is low, but control mode has an effect (?)

Latch Preload During Deployment Phase



Multiple Deployment Cycles Show Preliminary Repeatability Data



Initial Deployment Repeatability Data is Encouraging

- These tests:

  Do not account for MEF motion relative to deployment ground (conservative overbound of actual repeatability)

  Are measurement at a single sensor location

  May not be fully thermally stabilized

  Do not include post-deployment induced microlurching for further stabilization ("mellowing")

- Nevertheless ...

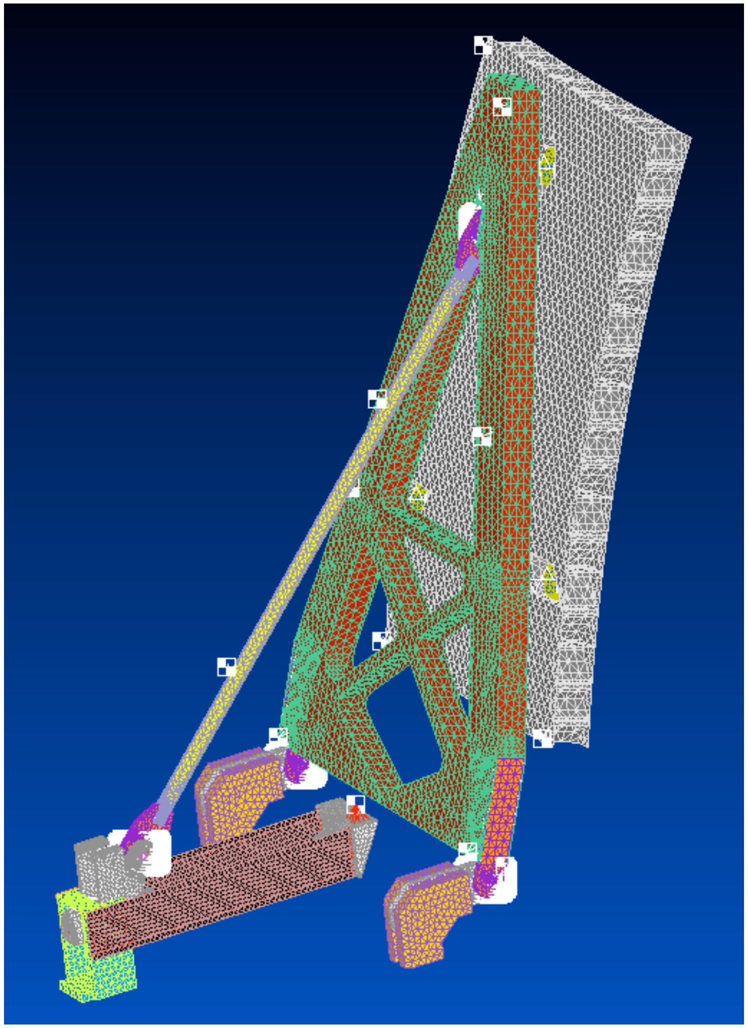
  Initial results are in the range of +/- 1-2 microns

- Current activities
  - Statistically significant data set collection
  - Data reduction (remove MEF bias)

  - Estimation of optical figures of merit

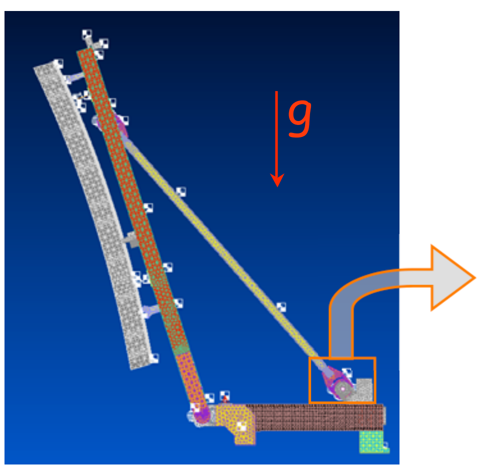
Complete SPTA Finite Element Model

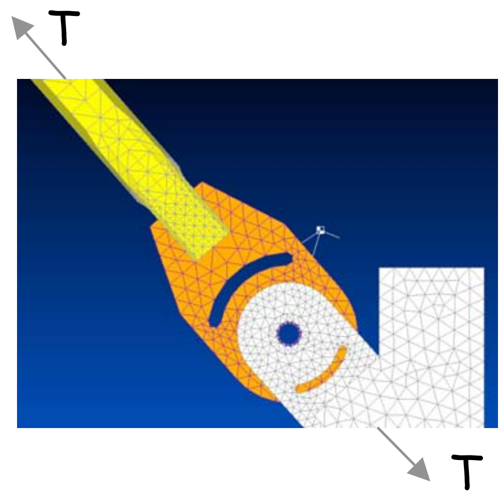
- Model being used to
  - Correlate with test data
  - Verify key theoretical assumptions
  - Extrapolate to flight system performance
- Current FE Model
  - 430,000 DOF
  - 110,000 Elements
- New nonlinear elements developed to model friction in the deployment mechanisms

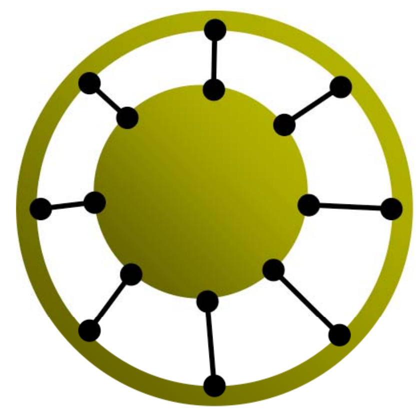


Bearing model captures friction and the effect of gravity on the deployment mechanisms

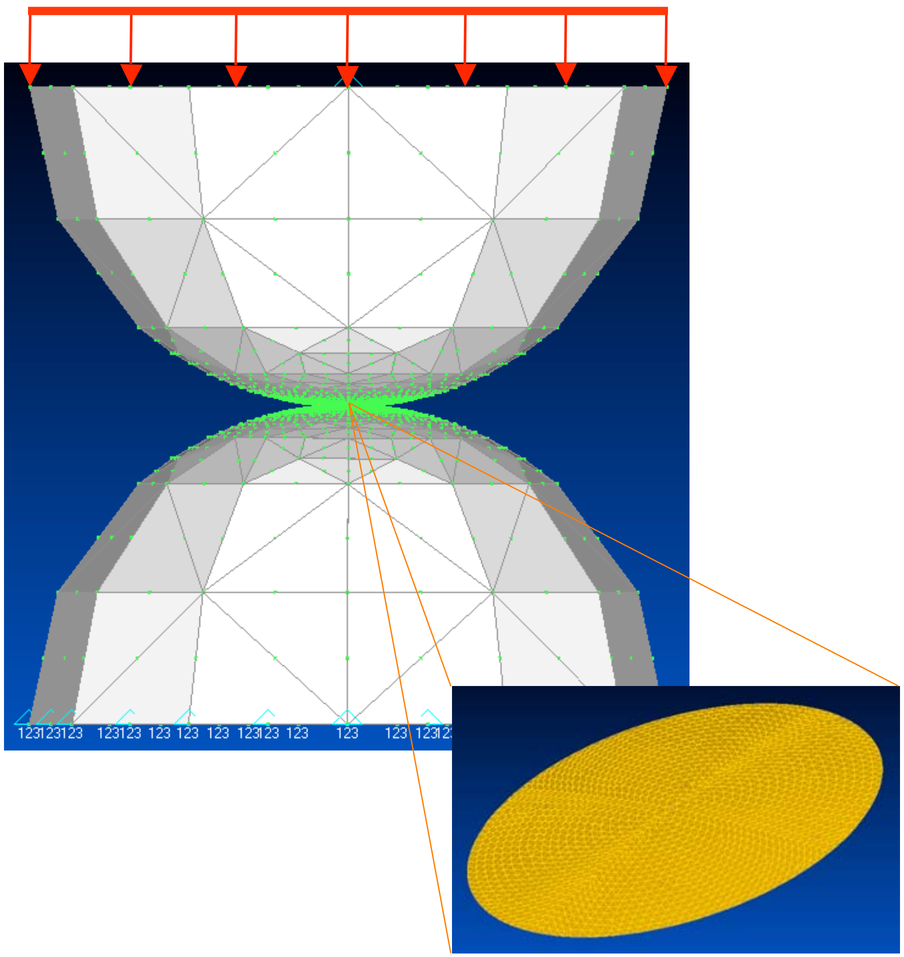
- Nonlinearities in the bearing contact cause different axial loading states under gravity loading.
- An accurate modal analysis requires the linear state of the bearings under a gravity load.
    - With a nonlinear static analysis, axial loading can be extracted and applied to an updated linear tangent stiffness K_t.



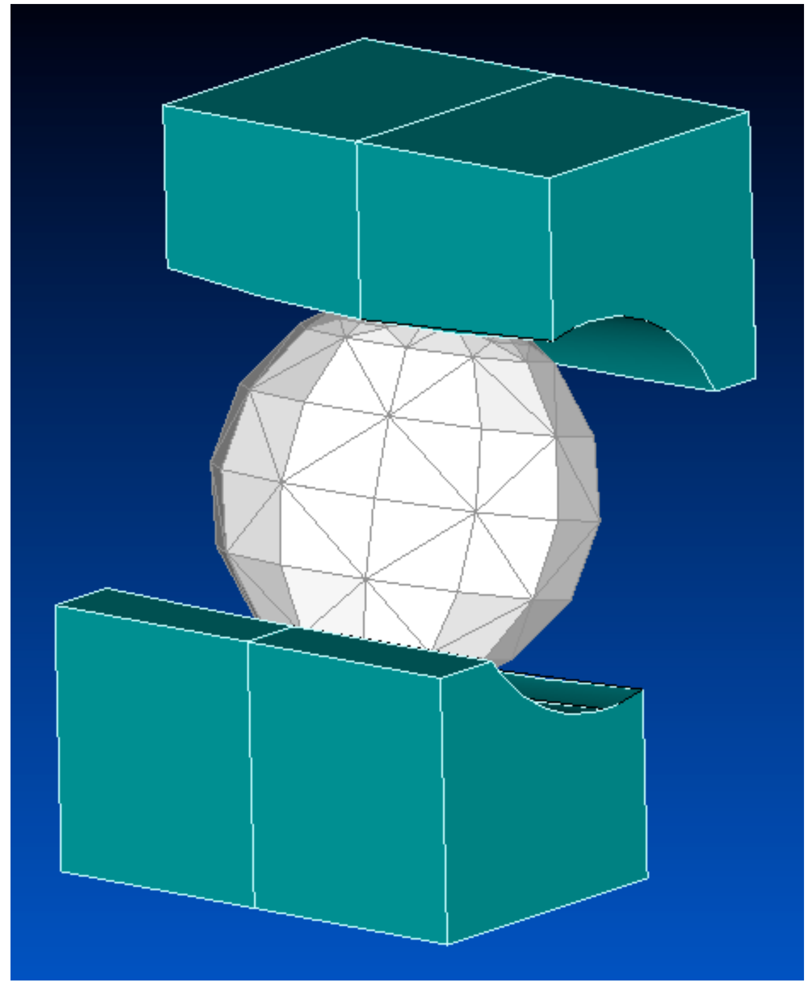




Bearing model embodies 6-DOF mechanics of more detailed contact patch mechanics



Contact Patch



Summary

- DOME is developing and verifying key technology for deployable optics
  - Low cost, low mass mechanisms with predictable behavior

    Behave as though the frictional interfaces were absent
  - Methods for progressing from component to sub-system to system models
  - Verified models of components and sub-systems
- Focus is on a concept for deployed, 2.5 meter lidar receiver
  - Technology applies to any deployed optic
- Provides basic technology for the "virtual verification" of large optical systems
  - Nonlinear mechanism models valid to nanometer level
  - Model and experiment uncertainty quantification
  - Verification of deployment repeatability and post-deployment stability
  - Predict on-orbit performance from 1-g experiments

Recommendations for Next Steps

- Deployable lidar receivers should be considered ready for flight system infusion
  - DOME is demonstrating deployment technology

    Passive deployment to lidar-adequate precision

    Modeling techniques adequate for virtual verification
  - Additional technologies have been developed elsewhere

    Low mass and low cost optics (diffractio

    Reflector packaging concepts

    Secondary tower packaging concepts

    Deployable thermal shield